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FAILURE OF BRASS. 3.—INITIAL STRESS PRODUCED BY THE "BURNING IN" OF MANGANESE BRONZE

By Paul D. Merica, Associate Physicist, and C. P. Karr, Associate Physicist

INTRODUCTION

The present investigation has been made in connection with the failure of a number of manganese bronze valve castings in the Catskill Aqueduct (New York), failures which are described briefly by A. D. Flinn, of the New York Board of Water Supply, as follows:[1]

* * * Until the spring of 1915 castings were believed to be immune from troubles, excepting those incident to foundry work and of the kinds which might occur in any metal. Since then, however, a number of castings from at least three different foundries producing manganese bronze have been found cracked. All of these castings, before acceptance, had been subjected to hydrostatic test pressures of 200 or 300 pounds per square inch, for a half hour or more, and, of course, appeared to be satisfactory at the time of preliminary acceptance. Some months later, after having been placed in the structures, some of these castings leaked under pressures of only a few pounds. In some castings the cracks have grown longer as time has elapsed, and in some, with the passage of time, additional cracks have been discovered. These cracks are fine, and often difficult to detect on the surface until the casting is put under hydrostatic pressure. In most cases, indeed, in nearly all, these cracks appeared to be close to or in a repair made by the method of burning in. * * *

The castings referred to above are quite large, up to 22 000 pounds in weight, such that neither preheating of the casting for the welding or burning in of defective areas, nor subsequent annealing of the whole casting could be conveniently carried out. As a result of the local heating of welding and consequent unequal contraction of different constrained parts of the casting, stresses remained in the casting, particularly severe near and within the

[1] A. D. Flinn, Some Experiences with Brass in Civil Engineering Works, Trans. Amer. Inst. Metals, 6; 1915.

burned-in areas; these stresses were in all probability responsible for the subsequent failure at these points.

The determination of the values of such stresses, in the case of castings of manganese bronze, in correlation with the physical properties and structure of this material as welded or burned in seemed desirable.

THE MEASUREMENT AND CALCULATION OF STRESS

For the investigation of these stresses a form of casting, shown in Figs. 1 and 2, was chosen. It is a double-bar frame, the two crossbars, *A* and *B*, having sections of area 1 by 1 inch and 3 by 3 inches, respectively, and being connected by heavy and stiff ends, *M* and *N*. The inside length from *a* to *b* (Fig. 1) of the bars was about 9 inches.

A portion of the bar *A*, varying from 1/4 to 2 inches in length, was removed by sawing and replaced by burning in with the same material, care being taken to keep the bar, *B*, cool during the

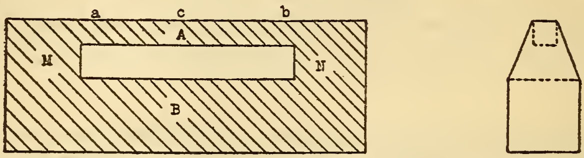

FIG. 2.—*Form of casting used in burning-in experiments*

operation. The pouring gate for the burning in was then sawed off, gauge points placed just inside of *a* and *b*, and readings taken with a strain gauge before and after sawing through *A*, outside of the gauge point, at either *a* or *b*. Knowing the elastic modulus of the material and the contraction over the 8-inch gauge length, a direct calculation gives the value of the stress in the bar *A*.

Some interest attaches to the method by which the welding was accomplished. In all cases the casting was placed on its side and embedded in green sand, a pit was then hollowed out by hand around the severed ends of *A*, such as to expose these ends, and the bar from 3/4 to 1 inch back, and to allow a small channel way, from 1/16 to 1/8 inch wide around the bar at these ends. The sand was here built up slightly and a hollow iron cylinder, about 4 inches high, set over this pit, thus providing a sufficient pouring head. It was found necessary to preheat the ends to be welded, not only by means of a torch but also by making a small reservoir in the sand directly under the burning-in pit, separated from it

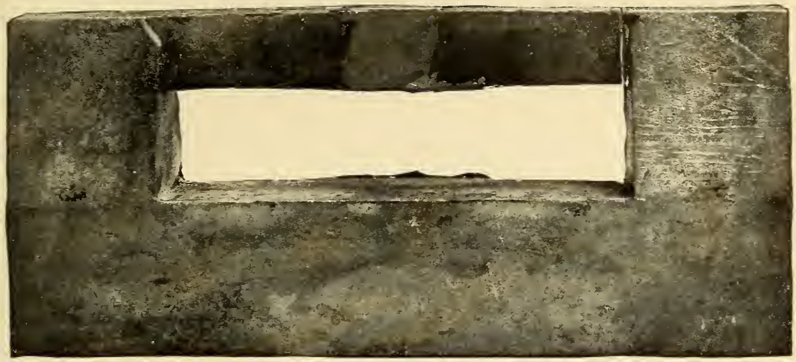

FIG. 1.—*Casting used in the burning-in experiments*

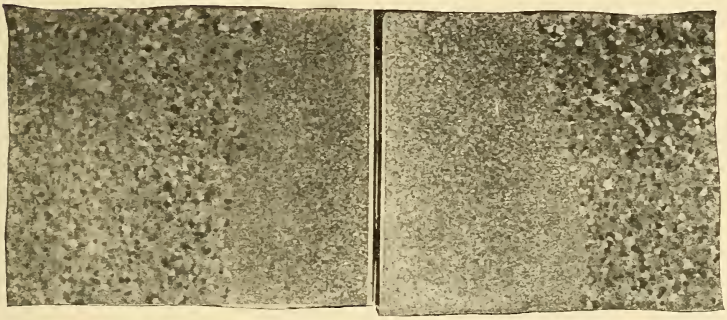

FIG. 3.—*Grain structure of section through burned-in zone. Etched with ammoniacal copper chloride.* ×1

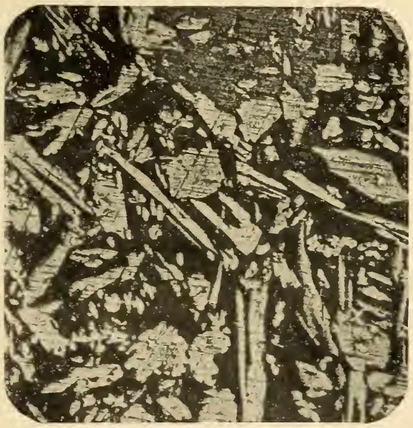

FIG. 4.—Outside of burned-in zone

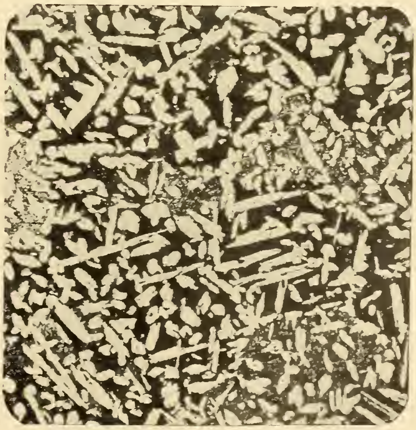

FIG. 5.—Within burned-in zone

FIGS. 4 and 5.—*Microstructure of burned-in bronze casting. Etched with ammonium hydroxide.* ×100

by sheet-iron plates, and pouring hot metal into this reservoir immediately before burning in. No flux of any kind was used.

The molten metal was first poured into this reservoir, then into the pit, completely enveloping the ends and filling the pouring head.

In order to be certain that the bar, *B*, of the casting was actually kept cool during the operation, this part was in several instances water-cooled while the weld was made. This was done by boring a 1-inch hole longitudinally through the center of *B*, attaching pipe and hose and running water through during the operation of burning in.

The material used was that of a large scrapped manganese bronze casting, kindly furnished by the New York Board of Water Supply, of the following composition:

	Per cent.		Per cent.
Copper	58.5	Lead	Trace.
Zinc	39.1	Iron	1.4
Tin	1.0	Manganese	None.

This method gave uniformly sound welds, as will be seen from Figs. 3.

TABLE 1

Stresses Produced by the Burning In of Manganese Bronze

Casting	Length of bar A, removed and burned in	Tensile stress measured after burning in	
		Lbs./in.²	Kg/ cm²
	Inch		
232a	0.25	9600	680
232b	.50	(2)	(2)
232c	.50	9200	640
232d	.50	8500	600
232e [3]	.50	8500	600
232f	2.0	6400	450
232g [4]	2.0	8500	600

[2] Weld not sound.
[3] This casting was locally annealed as described below before the stress determination was made.
[4] In this case the part *B* of the casting was cooled with running water as described above.

Table 1 gives the values of the tensional stresses found in the bar *A* of the various castings tested.

It is now not difficult to make an approximate calculation of the tensile stress in the bar *A*, which should result from the burning in.

Let E = the modulus of elasticity of the material (in tension),
$E' = f$, (E, geometry of object to be burned in) = the reciprocal of the fractional elongation per unit stress, between a and b, of the frame, $M\ B\ N$
l = the distance from a along A toward b
L = the distance $a\ b$
S = the resultant unit stress along A, due to burning in.

At the moment of burning in—i. e., of the solidification of the burned-in metal—the temperature distribution along A is given by

(1) $t = \phi(l)$

and

(2) $l = \psi(t)$, gives the equation of linear expanson of the material.

Then in cooling down to room temperature, 20° C, a change of length will occur between a and b, equal to

ΔL = −(amount of thermal contraction) + (elastic elongation due to the constraint by the bar B)

also

= −(elastic contraction due to the constraint by A)

$$= -\int_b^a dl \int_{t=20^\circ c}^{t=\varphi(l)} \frac{dl}{dt} dt + \frac{LS}{E}$$

$$= -\frac{LS}{E'}$$

Therefore,

(3) $$-\frac{LS}{E'} = \frac{LS}{E} - \int_b^a dl \int_{20^\circ c}^{\varphi(l)} \frac{dl}{dt} dt$$

(4) $$-\frac{LS}{E'} = \frac{LS}{E} - \int_b^a dl \int_{20^\circ c}^{\varphi(l)} \psi'(t) dt$$

The assumption has been made that at every moment during cooling of the bar A the resulting stresses have been below the elastic limit of the material. The equation (4) gives the general case and can not be solved unless $\varphi(l)$ and $\psi(t)$ are known. Assuming that the coefficient of linear expansion is constant—i. e., does not vary with the temperature—and equal to α, and that a length of

bar A, equal to d, was, at the moment of solidification of the metal, at the melting point of the metal, about 900° C, the equation (4) reduces to

$$L\frac{S}{E}-880\alpha d=-L\frac{S}{E'}$$

An approximate calculation of the stiffness of the frame $M\ B\ N$—i. e., the heavy bar and ends—gives

$$\frac{L}{E'}=\left(\frac{1}{E}+\frac{L}{9E}\right)$$

(considering the ends M and N as beams)
Therefore,

$$S=\frac{7920E\alpha d}{10L+9}$$

Assuming that

$E=15\times10^6$ pounds per square inch.
$\alpha=0.00002$
$L=9$ inches.
$d=1.5$ inches.
$S=36\ 000$ pounds per square inch.

One should expect, then, a tensile stress of about 36 000 pounds per square inch for every inch of metal burned in in these tests. There results, actually, a stress of from 8000 to 10 000 pounds per square inch, irrespective of whether ¼ inch or 2 inches of the bar A were burned in. This indicates, of course, that at some temperature the resulting stress becomes greater than the elastic limit of the material, and the material yields thenceforth, the stress following (with probably some time lag) the elastic limit of the material, such that the stress, as measured, one or two days after burning in, represents the true elastic limit of the material.

PHYSICAL PROPERTIES AND MICROSTRUCTURE OF BURNED-IN BRASS

A tensile test was carried out on a specimen from the bar A of No. 232g, and gave the following results:

Ultimate strength	60 000 lbs./in.^{2} (4220 kg/cm^2)
Proportional limit	13 000 lbs./in.^{2} (920 kg/cm^2)
Modulus of elasticity	15.4×10^6 lbs./in.^{2} (1.1×10^6 kg/cm^2)
Elongation in 5 inches	19.4 per cent.
Reduction of area	26.0 per cent.

The fracture occurred outside of the welded area, but not at the juncture of the original and the welded-in portions, and the

welded-in section of the test piece was harder and less elongated than the original material. The fracture showed only a few minute flaws; it may be accepted, therefore, that the true elastic limit of the material was somewhat below the proportional limit in this case.

Consideration of the microstructure of the burned-in metal affords an explanation for its greater hardness. Fig. 3 shows the grain structure within and without the welded-in area of the specimen 232c. It is seen that the central welded portion is of much finer grain than the original material, as cast, on either side, and the transition from welded to original structure is very abrupt. In Figs. 4 and 5 are shown the microstructures, inside and outside, respectively, of the burned-in zone. The structures are those of normal manganese bronze, there being no difference in the two other than that of size of grain. No evidence of overheating or of burning out of the zinc near the juncture of the zones was noted. These results may be compared instructively with those obtained by Carnevali,[5] on similar alloys, in which the welding was done by means of the oxy-acetylene flame. In this case a burning out of the zinc took place at the juncture of the weld. It is not surprising to find such differences in the results by the two methods, as greater opportunity for oxidation and overheating is given by the use of the oxy-acetylene process.

The bar *A* of casting 232h, with 2 inches burned in, was brushed over continually with a solution of mercurous nitrate for about two weeks, but showed at the end of that time no fissures or sign of failure.

A small portion, about 6 inches, of the bar *A* of the casting 232e was wound with Nichrome wire and the bar *A* thus locally annealed at a temperature of 300° C for about one hour. The stress in the part *A* remained unchanged by this treatment. It may be noted that if it is wished to relieve the stresses in *A* by some "heat treatment" affecting it only, the part *B* being kept at the ordinary temperature, the part *A* should be cooled 50° or 100° instead of being heated.

CONCLUSIONS

The experiments described have indicated how readily severe stresses may be introduced into a casting by the burning in or welding of a "constrained" area or portion of it. The form of

[5] F. Carnevali, Autogeneous Welding of Copper and its Alloys, J. Inst. Metals, 8, p. 282; 1912.

casting used in these experiments was such that no bending or distortion, tending to relieve the stresses, was possible during cooling, and this must be borne in mind in applying these results to the consideration of the effect of burning in of more complicated shapes, where such distortion does occur.

In the spherical shell or dome-shaped valve castings of the New York Board of Water Supply, for instance, burned in would tend to flatten the shell, and in so doing partially relieve these stresses, and it is most difficult to calculate the stresses in such a case. The authors are inclined to believe that even in these cases local stresses of values equal to the true elastic limit must have been produced and which would account for subsequent failure.

The conclusions to be drawn therefore are:

1. That the welding in of constrained portions of castings (forgings, wrought articles, etc., naturally, as well) of manganese bronze, produces, in general, local initial tensional stresses within and near the burned-in zone, of value equal to the true elastic limit of the material unless the shape of the casting is such that extensive distortion may occur.

2. That such castings should therefore be either preheated carefully for welding, such that all parts of the casting cool down together from a dull red heat or the casting should be subsequently annealed. Experience [6] indicates that a low temperature anneal is sufficient for this purpose—e. g., from 400 to 500° C (760° to 940° F)—for from one to two hours. Either of these precautions should eliminate these local stresses resulting otherwise from the burning in and should produce castings free from danger of subsequent cracking.

The authors wish to express their appreciation of helpful suggestions received in conference and correspondence with Messrs. A. D. Flinn, S. W. Miller, and others.

WASHINGTON, July 12, 1916.

[6] P. D. Merica and R. W. Woodward, Failure of Brass. 1.—Microstructure and Initial Stresses in Brasses of the Type 60 per cent Copper and 40 per cent Zinc, B. S. Tech. Paper No. 82.

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